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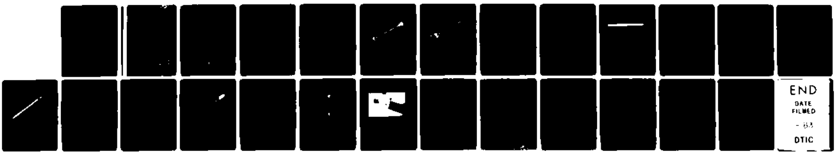

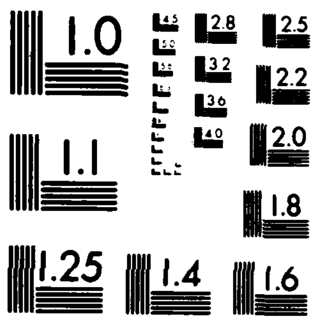

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Mechanical Engineering Technical Memorandum 412

MANUFACTURE OF A HOT WIRE TARGET ELEMENT FOR A CLOUD LIQUID WATER CONTENT METER

N.J. REPACHOLI

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Mechanical Engineering Technical Memorandum 412

MANUFACTURE OF A HOT WIRE TARGET ELEMENT FOR A CLOUD LIQUID WATER CONTENT METER

Neil J. REPACHOLI

SUMMARY

An Instrument has been developed to measure the liquid water content of artificially generated and naturally occurring icing clouds during ground and flight anti-icing trials of the Nomad N24 aircraft.

This report describes the techniques employed in the manufacture of the hot wire target elements used in the liquid water content meter.

POSTAL ADDRESS: Chief Superintendent, Aeronautical Research Laboratories, P.O. Box 4331, Melbourne, Victoria, 3001, Australia.

CONTENTS

1. INTRODUCTION

Anti-icing trials were conducted in 1979 with a Nomad N24 aircraft, [see Atkins, 1981]. In-flight measurements were required of the liquid water content in the airstream entering the engines when operating in natural or in artificially - generated icing cloud conditions.

While developing instrumentation to measure airstream liquid water content (LWC), some problems were encountered in the manufacture of suitable hot-wire target probes. The probes had to be robust, easily replaced and, for repeatability of results, the response of individual probes to airstream LWC was required to be very similar. Full details of the LWC instrumentation are given in Skidmore et al., (1982). The method employed to manufacture the probes is described in this Report.

2. DESCRIPTION OF THE HOT-WIRE TARGET PROBE

The hot wire target probe was based on a design, shown in figure 1, developed by the Commonwealth Scientific and Industrial Research Organisation, (CSIRO) [see King et al. (1978)]. The airstream LWC is measured by using, as a target, a constant temperature hot-wire element which forms one arm of a Wheatstone Bridge circuit. The power required to maintain the wire at a constant temperature, thereby balancing the heat transfer loss from the wire to the airstream, gives a measure of the LWC. However, in order to meet Department of Transport (DOT) standard airworthiness acceptability tests, further development of the CSIRO probe was necessary. Operation of the LWC sensing head and metering instrumentation under the following conditions was required by DOT:

a) ENVIRONMENTAL

Operating temperature:	-35°C to +40°C
Relative Humidity:	up to 100% with heavy condensation
Vibration:	A power spectral density of $0.01g^2/Hz$ in the bandwidth of 0 to 2 KHz.
Altitude:	0 - 20,000 feet.

b) MECHANICAL

The equipment must remain secure in the event of a 10 g deceleration and be as small as practicable.

The CSIRO probe uses a double ended configuration (figure 1) with electrical connections being taken out through simple plugs of a non-aircraft design. This probe was difficult to remove from the housing and ice build up tended to occur not only on the unheated Araldite end fillets but also on the "flying leads" around the outside of the probe

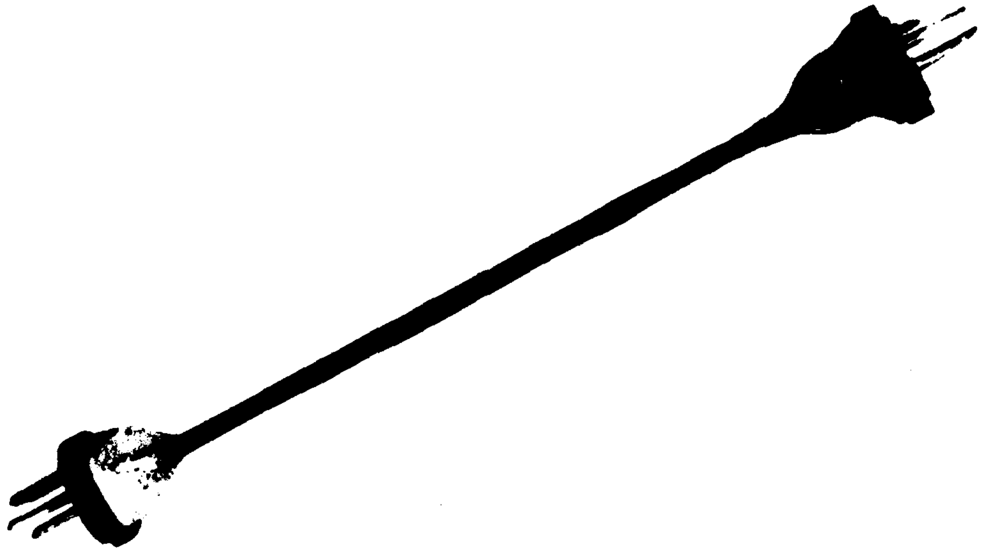


FIG.1 CSIRO DESIGNED TARGET ELEMENT

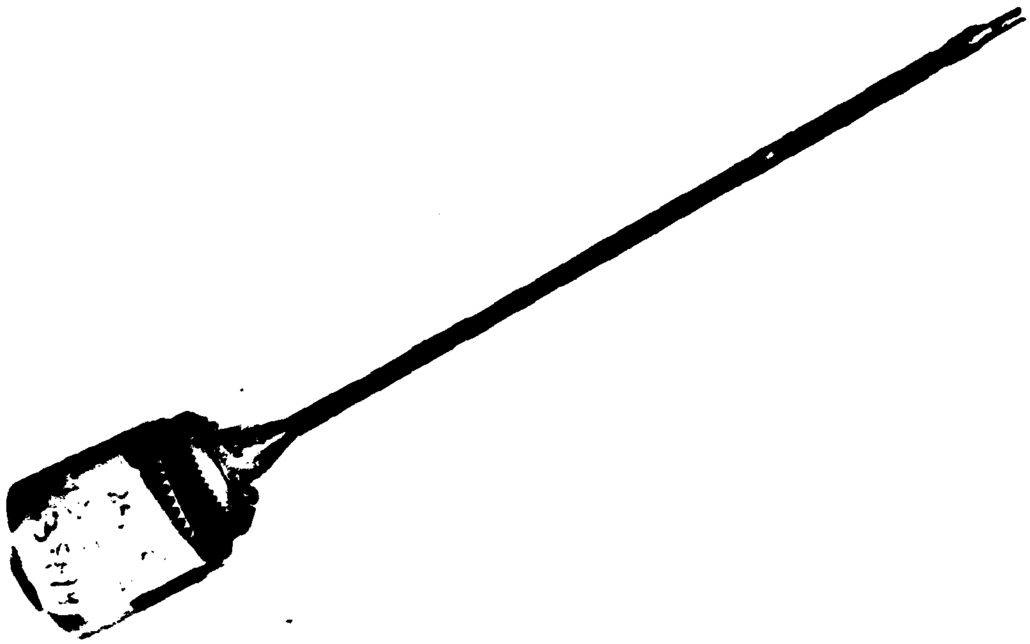


FIG.2 ARL DESIGNED TARGET ELEMENT

housing. These leads were needed to electrically connect the outboard plug.

To overcome these problems a new design based on a single ended configuration was adopted. This is shown in figure 2. It allowed elimination of the outboard plug, termination of all windings in a recessed Cannon connector and provided a simple means of support for the outboard end of the probe.

The actual target consists of a coil of double enamelled copper wire 0.102 mm in diameter (42 SWG), closely wound on a 1.6 mm diameter cupro-nickel supporting tube of 0.16 mm wall thickness. The main element was 38 mm long with a 19 mm slave or guard winding at either end. The purpose of the slave windings was to minimise axial heat losses from the target element. Nominal resistances were 3.75 ohms for the target element and 1.87 ohms for each slave winding.

This design was more robust than the CSIRO probe, interchange of probe elements was easier and most of the areas causing ice buildup were removed. In addition, it permitted the insertion of a small thermocouple into the bore of the support tube to provide a measure of the preset element winding temperature during calibration.

3. MANUFACTURING PROCEDURE FOR THE TARGET PROBES

Using 1.6 mm diameter cupro-nickel tubing and 0.102 (42 SWG) diameter double enamelled copper wire, the recommended procedure for manufacturing the probe and probe head assemblies is as follows.

3.1 Insulation between coil and tubing

The cupro-nickel tubing forms part of the earth return circuit of the master and slave windings and so insulation between tubing and windings is necessary. Five Minute Araldite is used as the insulator as it is capable of withstanding the heat generated by the surrounding copper coil. The procedure is:-

(i) Coat the cupro-nickel tube with a thin smear of Five Minute Araldite epoxy resin.

(ii) Apply mild heat to thin the Araldite and ensure a smooth finish of uniform thickness.

3.2 Slave winding - First half

This winding is 19 mm long with about 160 turns (see figure 3) and sufficient leadout to reach the connector end of the tube. The procedure is:-

(i) Carefully wind the first half of the slave coil ensuring that the insulation of the copper wire does not crack and that the turns are placed neatly against each other.

(ii) Use a small dot of polyurethane lacquer to secure the start of the winding and the lead-out. Allow about 5 minutes for the lacquer to dry.

Best results were obtained by winding the wire slowly by hand to avoid overlapping turns or gaps, then temporarily securing the leads while the master and second half of the slave coils were being wound.

3.3 Master Winding

This winding is 38 mm long with 320 turns. Sufficient wire should be allowed for the lead-in to reach the non-connector end, and for the lead-out to reach the connector end. The procedure is:-

(i) Wind the master coil, beginning hard up against the end of the first half of the slave winding.

(ii) Secure the leads with a dot of lacquer.

3.4 Slave winding - Second half

This winding was identical to the first half of the slave winding except that both leads required sufficient length to reach the connector end of the probe. The manufacturing technique for this winding is the same as that given in section 3.2.

3.5 Protective external coating

A coating of polyurethane lacquer is applied to hold the windings firmly in place and to provide target and slave windings with some protection against solid particles, such as ice fragments, which could be encountered in some operating conditions. A thin coating of lacquer about 50μm thick or less is recommended by King et al. (1981) because excessive coating thickness causes premature saturation of the target element. The coating thickness is also directly related to the thermal lag of the instrument. A low thermal lag allows rapid response to changes in liquid water content. Using a polyurethane lacquer, the ARL target element had an average coating thickness of 11μm. The completed master and slave windings are shown in figure 4. The polyurethane coating thickness measurements are shown in figure 5.

FIG.3 COIL AFTER FINISH OF FIRST SLAVE WINDING

3.6 Earth connection for master and slave windings

A solder joint (figure 6) between the winding leads and the cupro-nickel support tube at the non-connector end allows the tube to act as an earth, thereby eliminating the requirement for two connectors. The procedure is:-

(i) Run the lead-out wire of the master winding and the lead-in wire of the second half of the slave winding along the back face of the probe to the non-connector end and fix with Araldite.

(ii) Remove an area of Araldite from the non-connector end of the tube to provide a clean surface suitable for soldering.

(iii) Carefully burn the insulation off the ends of the two wires and soft solder to the tube as close to the windings as possible, leaving at least 1cm clear at the extreme end of the tube for end support of the probe in the housing assembly.

The following points should be noted:

(i) Use as little Araldite as practicable and ensure that none of it encroaches onto the front surface of the probe.

(ii) Ensure while soldering, that the heat does not burn the insulation on the windings.

(iii) Use the minimum amount of solder practicable because an uneven or bulging surface tends to attract ice build-up.

(iv) Take particular care to avoid dry joints when soldering as this extra resistance is in addition to the sensing resistance and decreases the sensitivity of the LWC meter.

3.7 Probe connector assembly

The probe assembly was completed by terminating in a Cannon type 407 CEAKPT06A8-4P connector. A short length of 0.71 mm (22 SWG) tin coated copper wire, soldered at one end to the inside of the probe tube and to terminal D of the Cannon plug at the other, provided a handy support between the probe and the connector to hold it in place while connecting the other wires. This arrangement also provided the means for aligning the probe axially with the connector and for adjusting the overall length of the probe assembly to the required length of 100 mm.

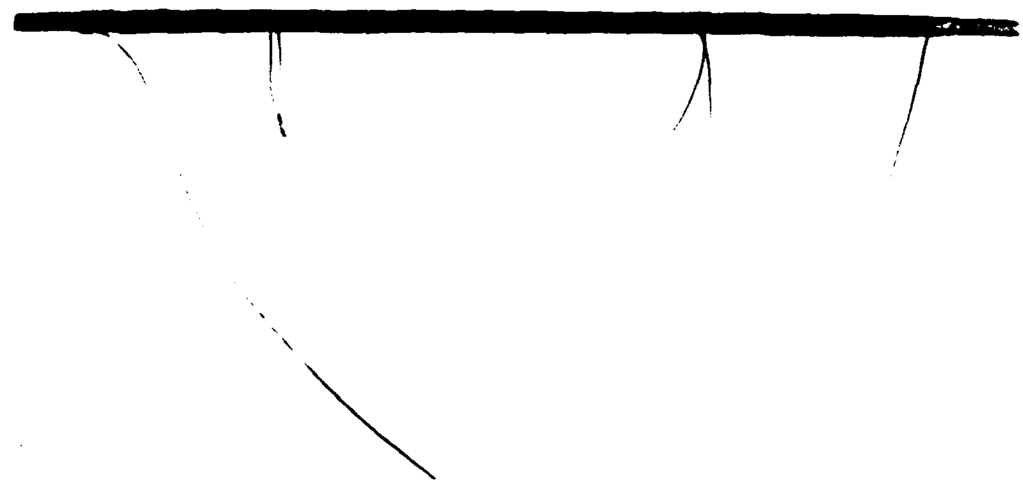
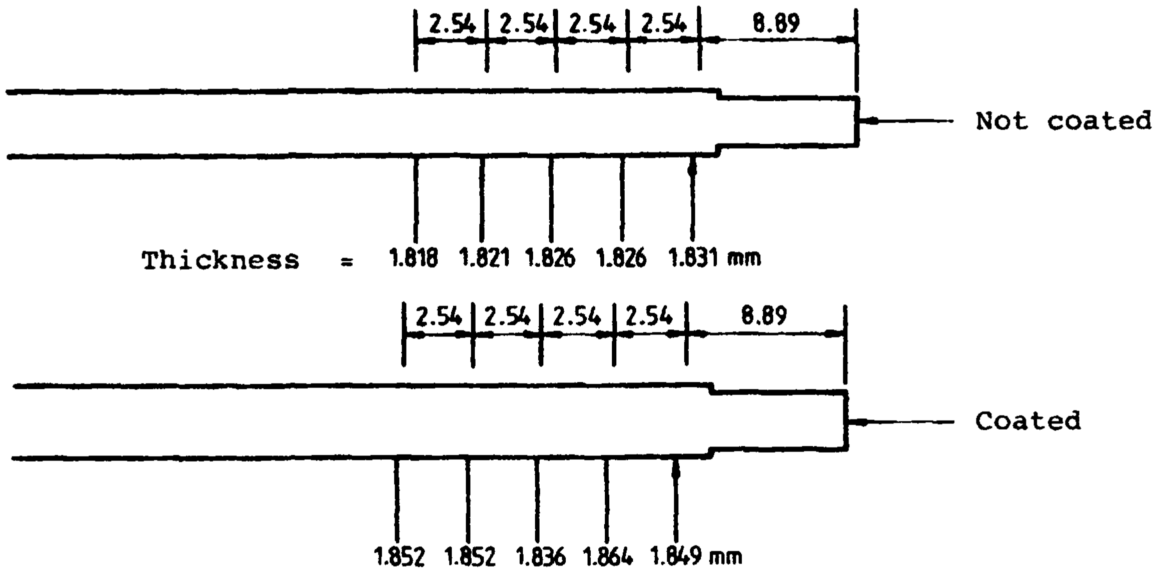


FIG.4 THE COMPLETE MASTER AND SLAVE WINDINGS



Average thickness of
coating on overall
diameter
11.4 μm

FIG.5 TARGET ELEMENT COATING TYPICAL THICKNESS MEASUREMENTS

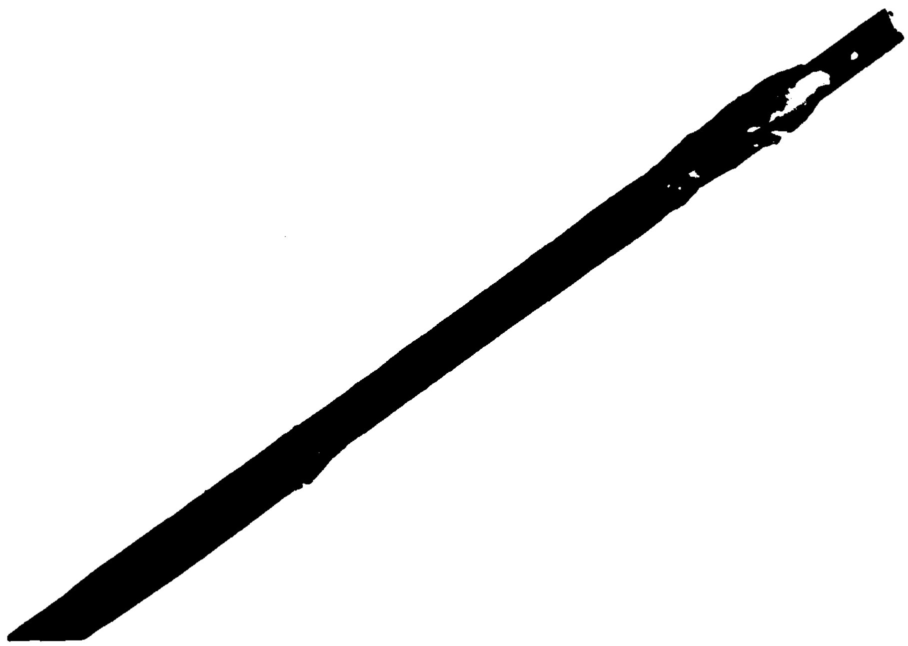


FIG.6 SOLDER JOINT FOR THE EARTH OF MASTER AND SLAVE WINDINGS

Terminal connections at the Cannon plug were:-

(a) master winding lead-in to terminal A.

(b) lead-in of first half of the slave winding to terminal B.

(c) lead-out of the first half of the slave winding and lead-in of the second half of the slave winding to terminal C.

(d) probe connector supporting wire [earth] to terminal D.

To complete the probe assembly at the connector end the following sequence is recommended.

(i) Run the remaining leads, i.e., those in a, b and c above, along the back face of the probe to the connector end and fix with Araldite.

(ii) Solder one end of the supporting wire to pin D of the Cannon plug and, adjusting for alignment and probe length, solder the other end to the inside of the probe support tube.

(iii) Solder the slave and master leads to the connector terminals as in a, b and c above, taking care to avoid dry joints and damage to the wires. The insulation is removed from the end of the wires by burning with a match and wiping away the residual carbon.

(iv) Carry out a resistance test between the connector pins to verify that there are no short circuits between master and slave windings and to check for correct resistances of the windings.

(v) Encapsulate the leads and pin connections in Araldite (ensuring appropriate separation between the leads) to form a secure conical shaped support as shown in figure 7. A presentable cone form may be obtained when shaping the Five Minute Araldite by slowly rotating the probe and turning it end on end, as required, to prevent the Araldite from either running down the face of the probe or from overflowing onto the connector.

(vi) Slip the securing cover nut over the body of the probe and screw to the Cannon connector.

(vii) Eliminate the possibility of earth loops by placing some nylon tubing, 1.5 mm inside diameter by 5 mm long, over the free end of the support tube to provide insulation from the probe housing at the outboard end of the probe.

4. PROBE REPLACEMENT

The sensing head assembly, i.e. probe and housing, used in the Nomad aircraft anti-icing trials is illustrated in figure 8. The completed unit shown mounted on a Nomad N24 aircraft in figure 9, was designed to enable probes to be easily changed in the event of winding damage or failure.

Probe interchange was simply accomplished by removing the cap nut shown in the assembly (figure 8), withdrawing the probe from the Cannon connector socket and the probe housing, then replacing with a spare.

A further requirement necessary to preserve instrument sensitivity when using different probes, was that the effective electrical resistances of individual elements agree within ±2.5%. Lead resistance between probe and instrument, junction resistances at connections and the resistance of the element winding itself all contributed to the total probe resistance. As the instrument worked by sensing changes in resistance it was important that all resistances other than the master winding had to be kept to a minimum. Lead resistances were kept to less than 1% of the effective element resistance by using 36 x 0.33 mm Teflon coated cable and taking special precautions to ensure successful solder joints. Individual element resistances were checked accurately to ±0.01 of an ohm and varied between 3.75 and 3.95 ohms. A separate resistance card located in the instrument box was required for each element so that the operating temperature of the wire could be accurately set at 91°C. Thus, when an element was replaced its resistance card was inserted into the liquid water content meter instrument box.

The complete circuit diagram for the LWC meter is shown in figure 10.

5. CONCLUSION

The completed target probes were used in over one hundred flight trials in the Nomad N24 aircraft anti-icing program; only one element was damaged. A test program carried out in the icing tunnel facility at ARL showed less tendency for ice to accumulate on the ARL probe than on a CSIRO type. This was important as ice accumulation affected the airstream velocity passing over the target element and hence altered the accuracy of the meter.

An external protective coating was applied to the target element to reduce its susceptibility to damage by ice fragments. It is important to keep the coating thickness to less than 50μm to avoid premature saturation of the target element and unacceptable thermal lags. One of the most important features of this probe was the achievement of a coating thickness of only 11μm using a polyurethane lacquer. The

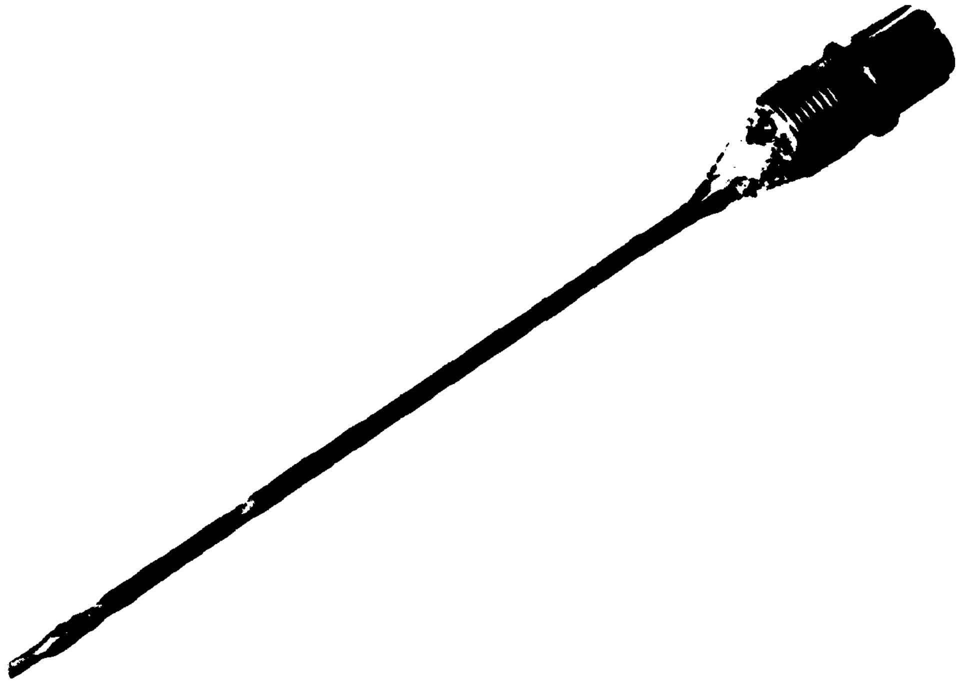


FIG.7 THE COMPLETED PROBE LESS THE SECURING NUT

coating thickness is a compromise between probe susceptibility to damage by ice fragments on the one hand and probe sensing range and reaction time on the other (see King et al. 1981).

Another feature of this design was the reduced amount of ice build-up on the probe compared with the original CSIRO double ended probe. This resulted in less disturbance to the airstream passing over the target area and hence greater accuracy.

Using an LWC meter based on a CSIRO design and target elements as described in this report, LWC's up to 3 gm/m³ at air velocities up to 66 m/s (see Skidmore & Pearce 1982) were measured.

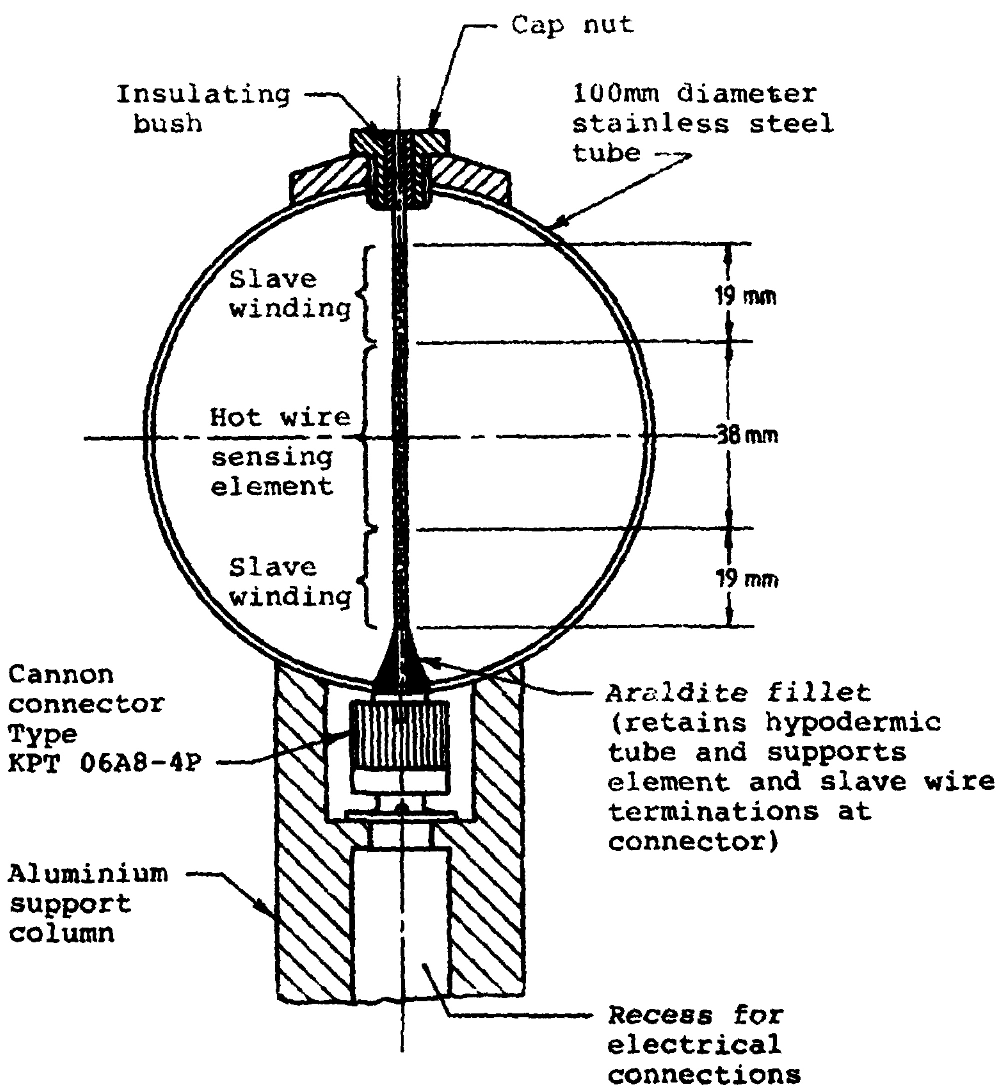


FIG.8 DETAILS OF SENSING HEAD ASSEMBLY FOR LIQUID WATER CONTENT METER

FIG.9 A.R.L. - G.A.F. SENSING HEAD ASSEMBLY

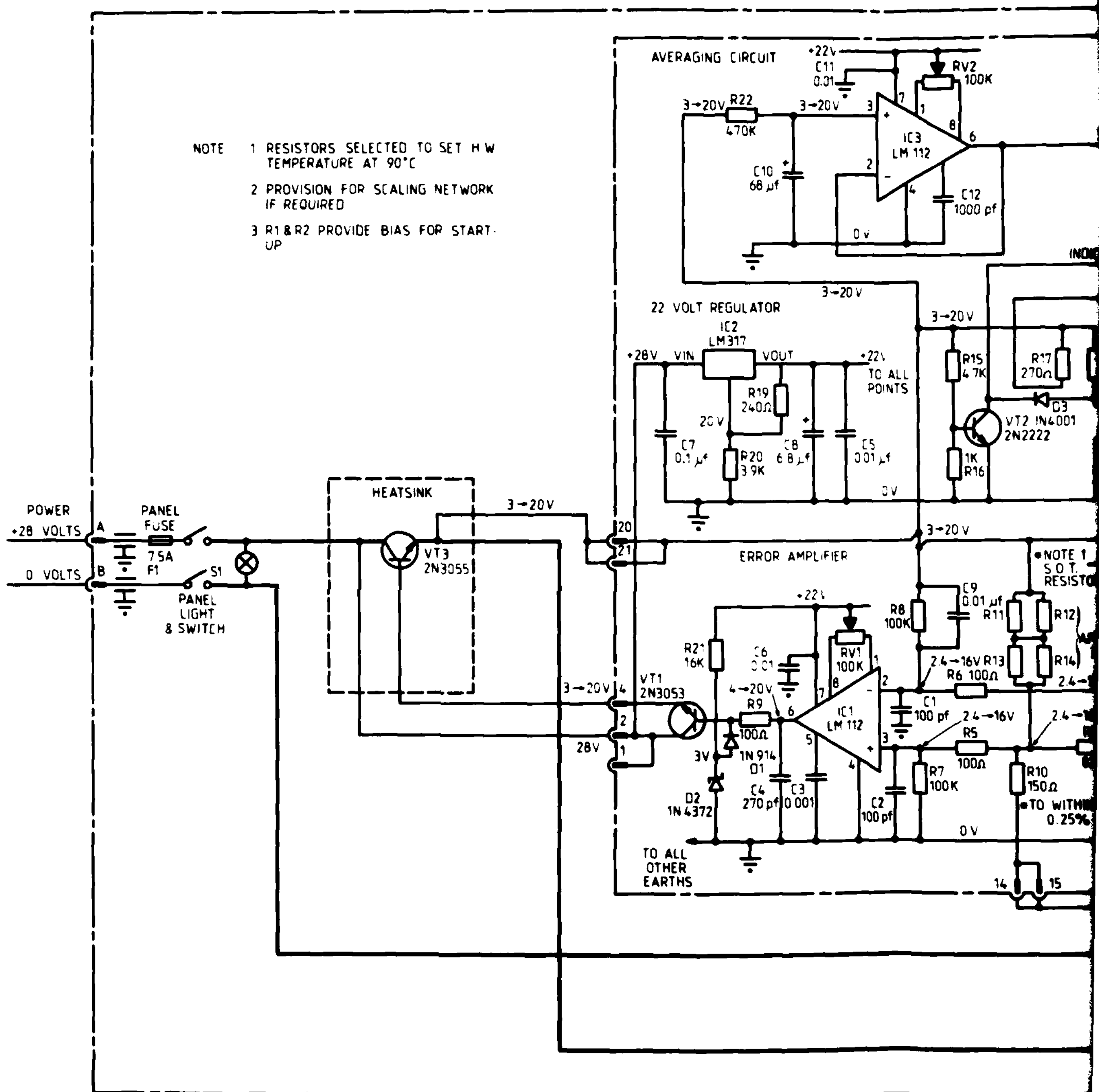


FIG. 10 LWC METER CIRCU

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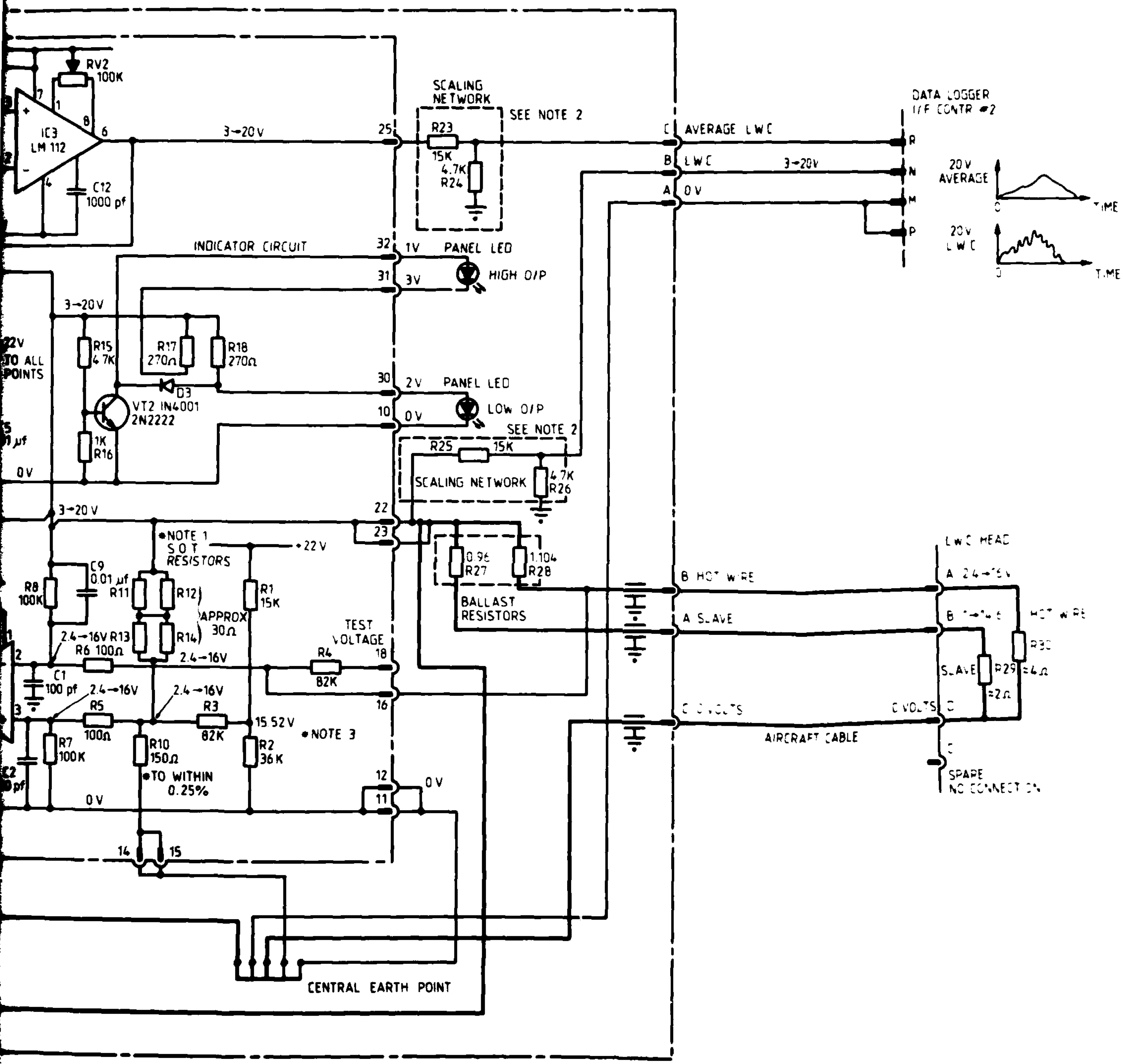
ANGLE PROJECTION
DO NOT SCALE



WC METER CIRCUIT DIAGRAM 2

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TOLERANCES | SCALE

LIQUID WATER CONTENT METER
ARL/GAF SYSTEM CIRCUIT DIAGRAM

56557 A1

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16.Abstract

This report describes the design and manufacturing techniques of a hot wire target element for a liquid water content meter, based on a C.S.I.R.O. design, which was used during Nomad icing trials in Australia and the United Kingdom.

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